A macroeconomic evaluation of a carbon tax in overseas territories: A CGE model for Reunion Island

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Abstract

Reunion Island, similar to most insular regions, is ruled by a carbon-based economy that is heavily dependent on fossil fuels. In recent years, the energy transition towards a low-carbon economy has become the watchword of this French overseas region, with the objective of a 100% renewable energy mix by 2030. Reducing fossil fuel use while maintaining economic growth is an important issue for all countries but is even more important for island territories with structural and geographical handicaps. Energy transition and drastic greenhouse gas emission reductions represent costs and opportunities that need to be quantified. This research paper assesses the environmental and macroeconomic effects of the carbon price policy introduced in France to meet the target of the Paris Agreement. The acceptability of the tax significantly depends on the possibility of recycling tax revenues. Different schemes for recycling tax revenues are considered in simulations. The methodology used is a computable general equilibrium (CGE) model for Reunion Island (GetRun-NRJ) that takes into account all island specificities. The results show that the carbon tax enables substitutions between fossil and renewable energy production and reduces CO_2 emissions. However, the tax has negative effects on the aggregate economy. The implemented tax revenue recycling compensation mechanisms mitigate the negative impacts, but the results differ significantly, as the recycling schemes do not support the same economic actors.

Keywords: Energy transition, computable general equilibrium model, carbon tax, Reunion Island, macroeconomic impacts.

JEL classification: O13, Q42, Q43, Q48

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1. Introduction

The will to implement an energy transition is part of the context of the awareness of environmental and climatic issues. Energy transition refers to a profound structural change in the energy production process and consumption, with the progressive abandonment of fossil fuel use and the development of renewable energy sources (RESs). The willingness to act is all the more important for island territories because they are particularly vulnerable to the effects of climate change due to rising sea levels and violent cyclones (Wolf *et al.*, 2016). The French overseas region of La Reunion, similar to most insular regions, is ruled by a carbon-based economy that is heavily dependent on imported fossil fuels. The energy sector is very complex. On the one hand, it is a driving force for economic development. On the other hand, it is also responsible for greenhouse gas (GHG) emissions due to the dependence on fossil fuels. Reducing the use of fossil fuels while maintaining economic growth is therefore a fundamental issue for all island territories.

French overseas territories have been experiencing rapid development, both demographically and economically. This dynamic is accompanied by a strong increase in energy demand. Today, French overseas territories have more than 2.7 million inhabitants, including 1.9 million in the overseas departments (DOM) and close to 800,000 inhabitants in overseas collectivities (COM) (INSEE, 2019). Reunion is the most populated region in overseas departments, with 883,325 inhabitants in 2019 (INSEE, 2019). In 2018, Reunion enjoyed strong economic growth of 3.2% (IEDOM 2019). To respond to these joint dynamics, these territories have had to rapidly deploy energy production for production and domestic use. They have mainly relied on fossil fuels (coal and fuel oil), which are increasingly expensive due to extra transport costs (Kuang *et al.* 2016; Wolf *et al.* 2016; Gilchrist R. 2014; Shirley and Kammen, 2013; Duić *et al.*, 2008). Consequently, their energy dependency ratio reached almost 90% on average (up to 95% in Martinique), compared to 50% in continental France, in 2012. For Reunion, the energy dependency ratio was 87.0% in 2017 (OER 2018).

Concerning energy, overseas territories are not or are only partially interconnected with the continental network. The French Act 2000-108 identifies the non-interconnected areas as non-interconnected zones (NIZs)[1]. These zones cannot import or export secondary energy. This strong constraint implies a closed network that is often weakly connected (with few connection points) and must maintain a constant balance between production and consumption, which makes it a fragile network (Notton 2015). However, due to their environment, which is rich in natural resources, these islands generally have the strong potential for diverse renewable resources, which proves to be a considerable asset (Selosse *et al.*, 2018a; Selosse *et al.*, 2018b; Timilsina and Shah, 2016; Praene *et al*. 2012).

Since the mid-2000s, the energy transition towards a low-carbon economy has become a clear objective for France and its overseas territories. France initiated its energy transition with the Environment Grenelle Forum (Grenelle laws 2007 and 2008) and more recently with the Energy Transition for Green Growth Law in 2015. The 2015 law established new targets for France as follows:

- reducing GHG emissions by 40% by 2030 compared to 1990,
- reducing the consumption of fossil fuels by 30% by 2030 compared to 2012,
- increasing the share of RESs to 32% of final energy consumption and to 40% of electricity generation by 2030,
- reducing final energy consumption by 50% in 2050 compared to 2012, and

[1] French NIZs consist of Corsica, Guadeloupe, French Guiana, Martinique, Reunion, Mayotte, Saint Pierre Saint-Martin, St. Bartholomew, French Polynesia, Wallis and Futuna, and the Breton islands.

- reducing the share of nuclear power to 50% of electricity generation.

For NIZs, the act requires energy autonomy by 2030, with an intermediate objective of 50% of renewable energies by 2020.

To meet the objective and internalize negative GHG emission externality, the French government introduced a carbon tax called "Climate Energy Contribution"[2] (CEC) in 2014. It takes the form of a carbon component directly integrated into existing taxes on fossil fuel consumption. The tax rate should increase progressively from 7€/tCO_2 in 2014 to 100€/tCO_2 in 2030 according to the Energy Transition for Green Growth Law (2015). However, recent social protests in France, known as the "Yellow Vests", in 2018 against the effects of the carbon tax on the increase in energy prices have moved the issue of environmental taxation acceptability back to the front of the stage. The carbon tax alone cannot entirely explain such social movement. However, the tax federated the resentment of part of the French population regarding the question of purchasing power in the context of a long stagnation of the purchasing power of middle-class households and of increasing petrol prices at the beginning of 2018 (Bureau *et al.*, 2019). Moreover, there was a growing mistrust of the French tax system, where the carbon tax was perceived as an additional tax intended to reduce the public deficit. Finally, these protests led the government to abandon the planned increase in the carbon tax for 2019.

Several studies have already analysed possible pathways for Reunion Island's energy self-sufficiency with bottom-up models (Selosse *et al.*, 2018a; Selosse *et al.*, 2018b; Drouineau, 201; Drouineau *et al.*, 2015; ARER, 2009). They have shown that Reunion Island is blessed with the high potential for renewable energies and that biomass energy plays an important role in the island's energy autonomy. However, despite the technical potential for energy self-sufficiency, energy transition does not occur mechanically. It is therefore the responsibility of public authorities to intervene. Economic analyses have long recommended carbon pricing as a cost-effective strategy for reducing greenhouse gas emissions and addressing the energy transition towards renewable energies. The High-Level Commission on Carbon Prices, chaired by Joseph E. Stiglitz and Nicholas Stern, recently concluded that achieving the goals of the Paris Agreement requires a carbon price of \$40-80/tCO_2 by 2020, rising to \$50-100/tCO_2 by 2030 (Stiglitz *et al*, 2017). This conclusion raises several issues. First, the use of a carbon price policy will represent significant costs and opportunities for the economy of Reunion Island that are important to quantify. Not all sectors of the economy will be impacted similarly; some will be penalized by rising energy prices, while others will benefit from investment in renewable energy sources (Boitier *et al*., 2015; Garabedian and Ricci, 2018). Moreover, is the carbon tax socially acceptable and fair? To date, several papers have investigated the distributive effects of energy taxes in France (Berry, 2019; Douenne, 2018; Combet and Méjean, 2017; Bureau, 2011; Ruiz and Trannoy, 2008). More specifically, the French carbon tax (CEC) is perceived by French people as penalizing rural and periurban households (Douenne and Fabre, 2020), and it is regressive; i.e., the poorer households are, the higher the CEC tax burden on household disposable income is when no revenue recycling is considered. The tax represents almost 1% of disposable income for the poorest 10% compared to 0.3% for the richest of the last decile (Bureau *et al*, 2018). In a context in which fuel poverty is taking on increasing importance in the public debate in France, introducing an additional carbon tax and questioning the use of tax revenues raise concerns over the fairness of the policy (Berry, 2019). However, a carbon price policy is essential to avoid more severe interferences with the climate system (Stiglitz *et al.*, 2017). The question of the acceptability of the carbon tax is the main challenge to be addressed by public authorities (Carratini *et al.*, 2018; Klenert *et al.*, 2018). The literature emphasizes that tax revenue recycling is a key element for the success of a carbon pricing policy from the points of view of acceptability, fairness and economic efficiency. The issue of the best recycling strategy has been the topic of a large and still growing body of theoretical and empirical

[2] In French, it is known as "Contribution Climat Energie".

literature. Three strategies have been deeply studied: the use of revenues to reduce other distortionary taxes on labour and capital in the economy and thus obtain a "double dividend" (Goulder 1995, 2013 and Bovenberg, 1999), the redistribution of revenues to achieve a fairer (less fiscally regressive) outcome via uniform lumpsum transfers or specifically targeting lower income or fuel-poor households (Klenert, David & Mattauch, Linus, 2016), and the green spending of revenues to support emission reduction projects.
For the French case, different revenue recycling schemes need to be considered. In 2017, the CEC generated revenue of 6.4 billion euros. It is not possible to precisely follow the usage of that CEC's revenues due to the principle of the non-allocation of budgets and because of the nature of the carbon component. The CEC is indeed a component of the fossil fuel tax (TIC) and not a tax in its own right. It seems that in France, the increasing revenues from the carbon tax have been mostly used to fund the budget rather than redistributed, which has caused limited public acceptance. However, the fossil fuel consumption tax revenues justify the identification of three approaches that can be used to design our revenue recycling scheme simulations. The first is the creation of an "energy transition" special account to partially finance renewable energy production. The second is lumpsum transfers to the most fuel-poor households via “energy checks”. The third recycling scheme is the use of tax revenues to finance the tax credit for job competitiveness (CICE) set up in France in 2013, where the objective was to boost the competitiveness of the private sector (Rogissart *et al.*, 2018).

In this paper, we propose the analysis of the macroeconomic impacts of the French carbon tax with different tax revenue recycling schemes on the economy of Reunion Island. To shed light on these issues, we have constructed a computable general equilibrium (CGE) model that takes into account the particular characteristics of the energy sector in an island setting and more precisely in Reunion Island. Computable general equilibrium (CGE) models have become a popular tool to assess this type of issue. Many studies use this methodology to evaluate the economic and social effects of a carbon tax with different scenarios for revenue recycling (Zhou *et al.*, 2018; Combet et Méjean, 2017; García Benavente 2016; Pereira *et al.*, 2016; Beck *et al.* 2015; Böhringer and Rutherford, 1997; Beuuséjour *et al.* 1995;; Whalley and Wigle (1991, 1992)). The first objective of the study concerns the construction of a model capable of representing the energy system in an island territory. The second objective consists of an evaluation of the macroeconomic and environmental impacts of the carbon tax with different revenue recycling schemes.

The article is organized as follows. In section 2, we present the energy sector and the economic and social context on Reunion Island. In the third section, we present the CGE model: GetRun-NRJ. Section four presents the scenarios and the simulation results. The final section discusses policy implications and provides concluding remarks.

2. Energy sector and economic and social context on Reunion Island

By increasing economic and climate vulnerability, the use of fossil fuels is one of the causes of the fragility of ultramarine territories. The transition to renewable energies seems to be quite urgent, from both an environmental and an economic point of view. However, while the ultramarine territories share many characteristics, they do not constitute a homogeneous whole in their progress in this transition. In this sense, Reunion Island is the most committed because it started programmes in 2000 that, today, include a share of renewable energies in electricity production that reach 32.4% (OER, 2018).

2.1 Reunion Island energy sector

Reunion Island consumes 1460.7 ktep of primary energy, for a final consumption of 1040.9 ktep. Primary energy comprises 87% fossil fuels and only 13% renewable energy (Figure 1). Forty-four per cent is devoted to secondary energy production (electricity and heat) and 56% to final consumption, of which 89% is for transport. As a result, almost all diesel fuel and half of the gasoline imported to Reunion Island are destined for transport, i.e., more than one-half of the primary energy supply. More specifically, fossil fuels consist of petroleum products (31.8%), diesel (28.5%), coal (25.1%) and gas (1.6%). They are almost completely imported since only used oils, which represent a very small quantity (1.3 ktep), are a local resource.

Petroleum products (gasoline, heavy fuel oil, jet fuel, used gas and oil) are mainly destined for final consumption (68.4%), notably in the transport sector (62.8%) and to a lesser extent in the tertiary sector (5.5%). The remaining 31.6% is used for the production of electricity (heavy fuel oil and waste oils). Coal is used exclusively for electricity production, whereas gas oil accounts for 98.8% of final consumption, either in transport (86%) or to a lesser extent in agriculture (12.9%); only a very small share is for electricity generation (1.4%).

Reunion Island alone produces almost one-half of the 405 ktep of renewable energy produced by all the NIZs (180 ktep). Renewable energies represent 25.2% of the secondary energy mix. Renewable energies include biomass, hydro, solar and wind. More than 99.8% of these resources are used for electricity generation or heat production. Biomass is an important item, accounting for 27.7% of renewable energy production in 2017. Biomass consists mainly of bagasse (96.3%) and, to a lesser extent, biogas (3.7%). It is used jointly for the production of electricity (31.2%) and heat (68.8%) in co-generation power plants and to a very small extent for final consumption by the tertiary sector.

Then, we have solar and hydro with 25.1% and 43.2% of renewable energies, respectively. Solar energy is one-half of photovoltaic electricity, and one-half of it is used for the production of heat. Hydro is allocated exclusively to power generation. Wind production is very marginal, constituting less than 0.01%, and no geothermal production is installed in this region (Figure 2).

In terms of efficiency, 714.8 ktep of primary energy are used to produce 291.1 ktep of secondary energy (electricity and heat) for an overall energy efficiency of 2.46[3]. However, this energy efficiency is specific to the different resources, and the results go from simple to triple. Coal appears to be the least efficient, with a coefficient of 3.82, followed by fuel and gas, with a coefficient of 2.27. Renewable energies are the most efficient, with a coefficient of 1.21 (considering that most of these energies have a coefficient of 1 when considering electricity production alone).

The energy dependence rate of Reunion Island is 87% (compared to 44.6% in continental France in 2018). This rate makes the island highly dependent on importation and vulnerable to world energy price fluctuations.

[3] Energy efficiency is obtained by relating the quantities of energy produced (electricity and heat) to the resources needed to produce them.

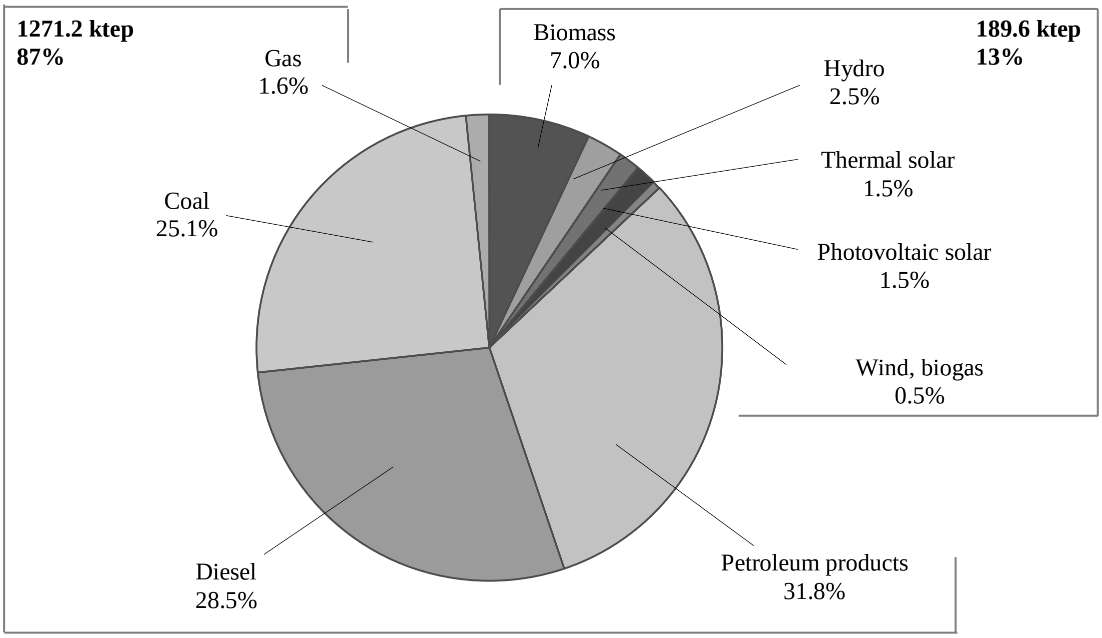

Figure 1. Primary energy consumption on Reunion Island (OER 2018)

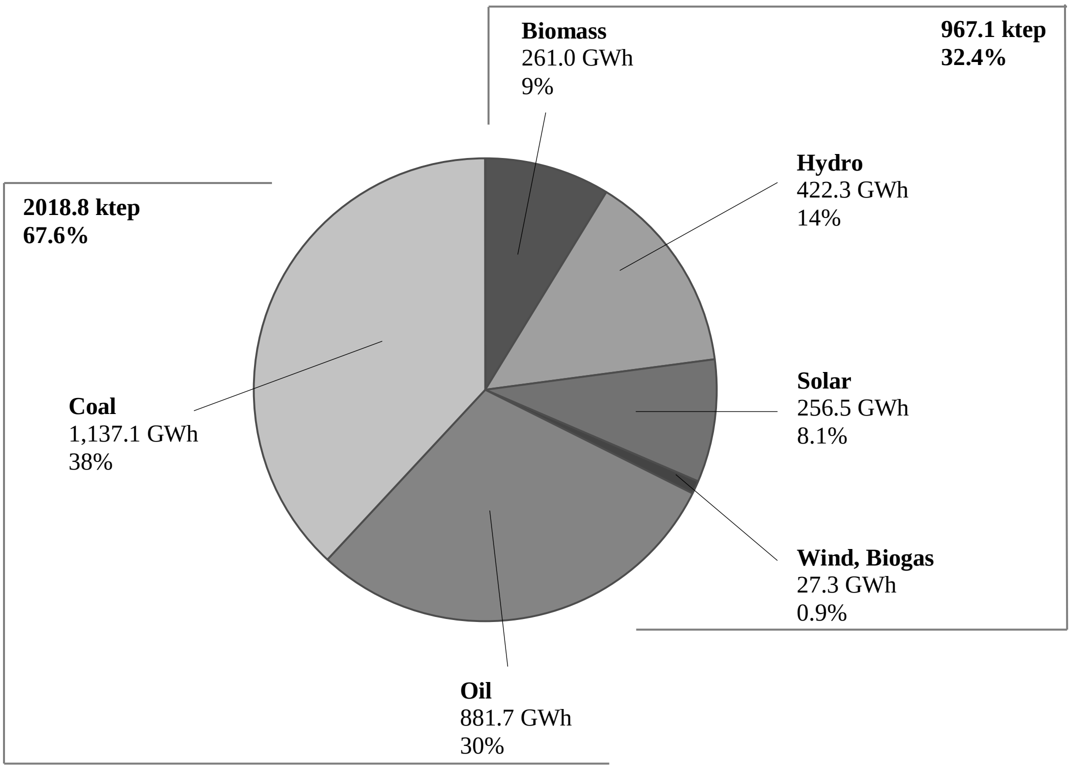

Figure 2. Electric mix on Reunion Island (OER 2018)

2.2 Reunion Island social and economic context

The standard of living is significantly lower on Reunion Island compared to mainland France. The average disposable income on Reunion Island is 1,508€ per month, 30% less than in mainland France, where it is 2,158€ per month. Social inequalities are also very important on Reunion Island; the richest 20% of Reunionese hold 42% of total income. Monetary poverty is more important on Reunion Island; 4 of 10 inhabitants live below the poverty line compared to 1.4 of 10 inhabitants in mainland France (INSEE 2018).

The first cause of a low standard of living is lack of jobs and insufficient income from activities. The latest survey on employment on Reunion Island, published by INSEE in 2018, shows that the unemployment rate of the population is 24% (increased from 22.4% in 2016), which is three times that in mainland France. Nearly 1 in 44 Reunionese are unemployed. The unemployment rate for young people aged 15 to 29 years is even higher, at 39.1% in 2017. Unlike in the previous three years, job creation was not enough to lower the unemployment rate in 2017 (23% in 2017). Employment in the market sectors has been less dynamic. The number of “subsidized contracts” has fallen sharply. “Subsidized contracts” are labour contracts for which the employer receives financial assistance that reduces the cost of labour. The majority of “subsidized contracts” concern the non-profit sector. In October 2017, according to the most recent data, 24,800 Reunionese benefited from a “subsidized contract”, 3,600 fewer than in the previous year (2016).

Poverty is also due to the structural and geographical specificities (insularity, remoteness) that have an impact on the cost of living. On Reunion Island, consumer prices are on average 10.6% higher than in mainland France according to INSEE data in 2017. Moreover, inflation is also higher. Prices increased by 2.5% on Reunion Island in one year compared to 2.2% in the same period in France.

By the end of 2018, all these difficulties led to a major social crisis in the territory and in continental France. Since November 17th, the Reunionese have manifested themselves through the movement of “Yellow Vests”, who are against the increase in fuel prices due to the carbon tax. Public authorities decided not to increase the carbon tax for the 3 years beginning January 1, 2019. The introduction of a carbon tax should therefore be accompanied by recycling measures. We propose to evaluate, with a CGE model, three recycling revenue strategies: to support the purchasing power of households, to facilitate the transition towards renewable energies and to support the employment rate.

3. CGE Model description

The computable general equilibrium (CGE) model developed to study the energy transition on Reunion Island (GetRun-NRJ model) is built on the work of (Decaluwé *et al*. 2001; Lemelin, 2008; Decaluwé *et al*., 2009; Robichaud *et al.*, 2012). This type of model is used to conduct a quantitative analysis of environmental policy implementation. Indeed, to carry out an environmental policy, it is not enough to know the nature and direction of the changes that result from the actions taken; we must also be able to quantify the impacts of these actions. The general equilibrium approach, unlike the partial equilibrium approach, provides a comprehensive representation of price-dependent market interactions based on Walras' equilibrium theory. CGE models can be static or dynamic. GetRun-NRJ is a static model for a single region (Reunion Island) with an underemployment issue. This model focuses on the energy sector, which has led us to disaggregate the production of secondary energy products (electricity and heat) into two sectors (the fossil and renewable energy sectors) and to disaggregate the use of fossil fuel products into intermediate consumption (for all sectors) and final consumption. Reunion Island being part of the non-interconnected zones (NIZs) implies an autarky of the energy sector in the sense that secondary production and consumption cannot be imported or exported. Moreover, the island is not endowed with fossil resources (gas, coal, or oil), which implies that the supply of primary fossil-based energy is fully imported, while the primary production of renewable energy is exclusively local. The model was calibrated with 2008 data.

3.1 Global Description

The basic structure of the model is characterized as follows (the interdependence mechanism is presented in appendix 1):

- A representative consumer
- A government
- A tax system on production, consumption and labour
- An open economy
- A labour market with unemployment
- 10 sectors (j): *agriculture, food industry, other industries, transport sector, fossil energy sector, renewable energy sector, building, service sector type 1 (trade, transportation, accommodation, catering, information, and communication), service sector type 2 (financial and insurance activities, real estate activities, and scientific and technical activities), and non-market service sector (administrative services, public administration, social security, education, human health and social action).*
- 10 products (i): *agricultural product, food product, other industries product, transport service, fossil fuel good, secondary energy product, building product, service type 1, service type 2, and non-market service.*

3.2 Production

The total output of all sectors j (XSTj) is a Leontief function of the value added (VAj) and intermediate consumption (CIj) of sector j, with technical coefficients, respectively, denoted by (v_j) and (oi_j).

$$VA_j = v_j * XST_j \quad (1)$$

$$CI_j = io_j * XST_j \quad (2)$$

There is a strict complementarity between the intermediate consumption of product i by sector j using a technical coefficient noted $aij_{i,j}$ (equation 3).

$$DI_{i,j} = aij_{i,j} * CI_j \quad (3)$$

The value added in sector j is a Cobb-Douglas function with a demand for labour LDj and a demand for capital KDj (equation 4).

$$VA_j = A_j * LD_j^{\alpha} * KD_j^{1-\alpha} \quad (4)$$

Thus, the demand for labour and capital of each sector j that maximizes the total profit is given by equations 5 and 6, which depend on the price of value added PVAj, the wage rate including the social taxes of sector WTj and the rate of return on capital in sector Rj.

$$LD_j = \frac{\alpha_j * PVA_j * VA_j}{WT_j} \quad (5)$$

$$KD_j = \frac{(1 - \alpha_j) * PVA_j * VA_j}{R_j} \quad (6)$$

3.3 Energy sector

The model particularly focuses on the energy sector on Reunion Island. Structurally and geographically limited in particular by their narrowness and remoteness from continents (Logossah, 2007), island territories face a closed network because they can neither import nor export secondary energy products; they are in non-interconnected zones. Their electricity distribution network is extremely fragile and has to ensure a constant balance between energy production and energy consumption. In addition, similar to most island territories, Reunion Island has no fossil fuels (coal, oil or gas) and must import these resources to meet its energy demand (Wolf *et al.*, 2016; Surrop *et al.*, 2018).

The energy sector is modelled in the GetRun-NRJ model to realize the characteristics previously announced specific to island economies. We divide the production of secondary energy products into fossil (NrjF) and renewable (NrjR) branches (sectors). This distinction is made according to the type of input used in the production process. Hence, the fossil fuel sector requires imported fossil fuel goods (coal and oil) as an important part of its intermediate consumption, while the renewable energy sector only uses them for operational purposes. Therefore, we have two different sectors in terms of production structure, which provide the same secondary energy product (electricity and heat). To allow for the possibility of disaggregating more specifically the types of energy production, we opt for a generalized CES function that lets us build production from different sectors by minimizing production costs (Lemelin, 2008).

$$DD_{NRJ} = A^{EN} * \left[\sum_j \beta_j^{EN} DS_{j,NRJ}^{\rho^{EN}}\right]^{\frac{-1}{\rho^{EN}}} \quad (7)$$

$$DS_{j,NRJ} = \frac{DD_{NRJ}}{(A^{EN})^{1-\sigma^{EN}}} \left[\frac{P_{j,NRJ}}{\beta_j^{EN} * PL_{NRJ}}\right]^{-\sigma^{EN}} \quad (8)$$

The fossil fuel good is also used by the transport sector as final consumption. Finally, to show the non-interconnected character of these territories (NIZs), the secondary energy product (electricity and heat) cannot be imported or exported. Formally, these specificities of the energy sector lead us to consider particular cases in the formation of local supply and demand. Indeed, when local production is non-existent, as in the case of the “imported fossil fuel” product, local demand will be fully supplied by imports. Symmetrically, if the product is not opened to the foreign market as in the case of the “secondary energy” product, then local demand will be entirely satisfied by local production.

3.4 CO_2 emissions

CO_2 emissions linked to household final fossil fuel consumption are calculated with the following equation:

$$EMS^m = em_{fr} C_{fr} \quad (9)$$

EMS^m represents the level of emissions generated by a household's final fossil fuel consumption, em_{fr} is a fixed emission parameter, and C_{fr} is the household consumption of fossil fuel products.

The emissions linked to the intermediate consumption of fossil fuels by each branch of production are calculated through the following equation:

$$EMS^b = em_{fr} DIT_{fr} (10)$$

Emissions (EMS^b) are generated by the intermediate consumption of fossil fuels in production process j, em_{fr} is the fixed emissions factor used in the previous equation, and DIT_{fr} is the total intermediate consumption of fossil fuels by all branches (in volume).

Total emissions (EMS^{tot}) are the sum of fossil fuel consumption emissions:

$$EMS^{tot} = EMS^m + EMS^b (11)$$

3.5 Income and Savings

Gross household income (YH) is composed of all income received (equation 12). These wages are from the sum of the demand for labour in each sector (LDj), which is remunerated at a single wage rate (W), the capital income from the sum of the demand for capital (KDj) remunerated at a specific interest rate (R_j) in each sector Rj, and government transfers (TG).

$$YH = W \sum_j LD_j + \sum_j R_j * KD_j + TG \ (12)$$

Disposable household income (YDH) is then gross household income reduced by direct taxes (DTH). Household savings (SH) is a fixed proportion of disposable household income. Consequently, the income for consumption (CTH) is the disposable income minus savings (equations 13, 14, 15).

$$YDH = YH - DTH \ \ (13)$$

$$SH = \psi TDH \ \ (14)$$

$$CTH = TDH - SH \ \ (15)$$

Government income is fed by the revenues from different taxes (equation 16). These revenues are from direct taxes (DTH), indirect taxes on each product (i) minus the subsidies paid on these products (TIi), social contributions levied in each sector j (CSj), taxes on sectors (j) minus subsidies on these sectors (TIPj), taxes on imports for sectors involved in international trade (TIMj) and carbon tax revenues (TEMS).

$$YG = DTH + \sum_i TI_i + \sum_j CS_j + \sum_j TIP_j + \sum_{tr} TIM_{tr} + TEMS \ \ (16)$$

Equations 17 to 22 provide more details about these taxes. The income tax (DTH) is a proportion (tyh) of gross household income.
Income taxes on products (TIi) are obtained by applying the VAT rate (tx) to local production exchanged on the local market (DDj), which is expressed in value excluding tax (PLj). In the case of exchangeable goods on the international market, we add to the income taxes on products the imports (IMi), which is expressed in value at the world price (PWMi) adjusted for exchange rate (e) and including customs duties (tmi).
The social contributions of each sector j (CSj) are a proportion (tcsj) of the wage sum of the sector.
Income taxes on production are obtained by applying the tax rate on production (tbr) to local production (XSj) at the out-of-factory price (Pj). Finally, the income from imports comes from the application of customs duty rates to imports in value terms.
Carbon tax revenues (TEMS) are the revenues from the carbon tax (t^c) applied to total emissions (EMS^{tot}).

$$DTH = tyh * YH \qquad (17)$$

$$TI_i = tx_i * \{PL_i * DD_i + [1 + tm_i] * e * PWM_i * IM_i\} \qquad (18)$$

$$CS_j = tcs_j * LD_j * W \qquad (19)$$

$$TIP_j = tbr_j * XS_j * P_j \qquad (20)$$

$$TIM_{tr} = tm_{tr} * e * PWM_{tr} * IM_{tr} \qquad (21)$$

$$TEMS = t^c * EMS^{tot} \qquad (22)$$

Government savings are obtained by deducting government expenditures (G) and financial assistance to the household (TG) from government income.

$$SG = YG - G - TG \quad (23)$$

3.6 Demand

Goods and services are intended for final consumption, intermediate consumption, investment or public consumption (equations 24 to 26). The volume of household final consumption is based on the assumption that the income share for each product (γ_i) is constant in the long term. This assumption is repeated for the volume of investment demand; the share of each product in the total investment (μ_i) is constant in the long term. The volume of the total demand for intermediate consumption of each product i (DITi) is the sum of the intermediate consumption of this product for each sector.

$$C_i = \frac{\gamma_i * CTH}{PC_j} \quad (24)$$

$$INV_i = \frac{\mu_i * IT}{PC_i} \quad (25)$$

$$DIT_i = \sum_j DI_{i,j} \quad (26)$$

Public expenditure per product does not correspond to a logic of maximizing profitability but to political decisions. As a result, the demand for public consumption by product is given explicitly in volume (GIi).

$$G = \sum_i PC_i * GI_i \quad (27)$$

3.7 Trade

Each sector j can produce one or more products i (XSj,i); then, the total output will be the sum of the production of each product. The sector chooses the production that maximizes its profit through a generalized CET function (equations 28 and 29) according to the price level of each product i of sector j (Pj,i) compared to the total price of the production of sector j (PTj).

$$XST_j = A_j^{XT} * \left[\sum_i \beta_{j,i}^{XT} XS_{j,i}^{\rho j^{XT}}\right]^{\frac{1}{\rho_{j,i}^{XT}}} \quad (28)$$

$$XS_{j,i} = \frac{XST_j}{(A_j^{XT})^{1+\sigma_j^{XT}}}\left[\frac{P_{j,i}}{\beta_{j,i}^{XT} PT_j}\right]^{\sigma_j^{XT}} \quad (29)$$

Moreover, each product i can come from different sectors j. Each product has two possible destinations: those resulting in a CET function of exports (EXj,i) and the local market (DSj,i). However, this function (equation 30) is not defined for all products but on a set i1 excluding product NRJ, which cannot be exported and whose production on the local market is dealt with in a specific way. When exports exist, their volume (equation 31) depends on the ratio of the producer's price of the exported good (PEi) to the pre-tax price of the product sold on the local market (PLi). Finally, equation 32 assumes that the local producer can increase its share in the world market only by offering a lower price (PEi^{FOB}) than the world price (PWXi).

$$XS_{j,i1} = A_{j,i1}^{E}\left[\beta_{j,i}^{E} EX_{j,i1}^{\rho_{j,i1}^{E}} + (1-\beta_{j,i1}^{E}) DS_{j,i1}^{\rho_{j,i1}^{E}}\right]^{\frac{1}{\rho_{j,i1}^{E}}} \quad (30)$$

$$EX_{j,i} = \left[\frac{1-\beta_{j,i}^{E}}{\beta_{j,i}^{E}}\frac{PE_i}{PL_i}\right]^{\sigma_{j,i}^{E}} DS_{j,i} \quad (31)$$

$$EXT_i = EXT_i^0\left[\frac{ePWE_i}{PE_i^{FOB}}\right]^{\sigma_i^{XD}} \quad (32)$$

Symmetrically, the local demand of product i (Qi) is a CES function of imports (IMi) and the demand for local products (DDi) when both exist (equation 33). Then, the volume of imports (equation 34) depends on the ratio of the net price (including indirect taxes) of the product sold in the local market (PDi) to the net price (including indirect taxes and customs duty) of the imported product (PMi).

$$Q_i = A_i^M\left[\beta_i^M IM_i^{-\rho_i^M} + (1-\beta_i^M) * DD_i^{-\rho_i^M}\right]^{\frac{-1}{\rho_i^M}} \quad (33)$$

$$IM_i = \left[\frac{\beta_i^M}{1-\beta_i^M}\frac{PD_i}{PM_i}\right]^{\alpha_i^M} * DD_i \quad (34)$$

The current account balance is the difference between the value of exports and that of imports (equation 35).

$$CAB = e * \sum_i PWE_i * EX_i - e * \sum_i PWM_i * IM_i \quad (35)$$

3.8 Price

The price equations are given by the following equations. The value-added price adjustment (PVA) is based on equations 1 and 2, which define the value added, taken back in value with the addition of the price of production including the taxes (PTj) and the index of intermediate consumption prices (PCIj). The PCI is then the aggregation by sector of the price of composite products (PCi) allocated to the demand for intermediate goods (DIi,j).

$$PVA_j = \frac{PP_j * XST_j - PCI_j * CI_j}{VA_j} \quad (36)$$

$$PCI_j = \frac{\sum_i PCI_j * DI_{i,j}}{CI_j} \quad (37)$$

The net prices are obtained by applying the taxes. The net price of the product sold on the local market (PDi) is the pre-tax price (PLi) to which the indirect tax rate (txi) is applied. The net price of the imported product (PMtr) is the international price adjusted for the exchange rate to which the indirect tax rate and customs duty rate (tm_{tr}) are applied.

The composite product price (PCi) is then the weighted average of PLi and PMi. The weights are the shares of the composite product volume (Qi) from domestic production (DDi) and imports (IMtr).

$$PD_i = [1 + tx_i] * PL_i \quad (38)$$

$$PM_i = [1 + tx_i] * [1 + tm_i] * e * PWM_i + [t^C * em_i] \quad (39)$$

$$PC_i = \frac{PD_i * DD_i + PM_i * IM_i}{Q_j} \quad (40)$$

The producer price (Pi) of the good is based on equations 29 and 30, which define the output of each sector, recovered in value, with the pre-tax price of the good sold on the local market (PLi) and the producer price of the exported good, which is assumed to be untaxed (PEtr) and which therefore depends only on the international price corrected for the exchange rate.

Finally, the general index of prices (PINDEX) is the aggregation of the value added of each sector according to the respective shares of each sector in the GDP ($delta_j$). The real wage rate of each sector (WTj) depends on the overall wage rate (W) to which the specific social contribution rate of each sector (tcs_j) is applied.

$$PINDEX = \sum_j \delta_j * PVA_j \quad (41)$$

$$WT_j = W * (1 + tcs_j) \quad (42)$$

3.9 Unemployment

The model assumes an underutilization of labour resources and hence the presence of unemployment. This unemployment is modelled by an unemployment/wage curve (wagecurve) (Blanchflower and Oswald, 1995), assuming a downward rigidity of wages (equation 46). According to the literature, the elasticity between the unemployment rate (UN) and the wage rate (W) is fixed at beta UN = -0, 1. Thus, the total demand for labour (LDT) is the aggregation of labour demands in each sector j (equation 43), and unemployment volume corresponds to the difference between this aggregate demand for labour and the total labour supply (LS) (equation 44). The unemployment rate (UN) is calculated as the share of unemployment in the total labour supply (equation 45).

$$LTD = \sum_j LD_j \quad (43)$$

$$CH = LS - LDT \quad (44)$$

$$UN = \frac{CH}{LS} \quad (45)$$

$$W = A^{UN} UN^{\beta^{UN}} \quad (46)$$

3.1. Equilibrium and Closure

The equilibrium conditions of the model are given by equations 47 to 50. The first condition represents domestic absorption, which respects Walras' general equilibrium theory, indicating that all markets must be in equilibrium. Thus, the local demand for each good and service must be absorbed by final consumption, intermediate consumption, demand for investment and public expenditure. The second condition assumes that the supply of local products must be equal to demand. There is a total use of the capital resource, which is specific to each sector (short-term equilibrium). Thus, the supply of capital by branch (KSj) is equal to the demand for capital by branch. Moreover, the labour resource is underutilized; there is unemployment, as described above. Finally, the total investment (IT) is the sum of savings: household savings, state savings and the savings of the rest of the world.

$$Q_i = C_i + GI_i + DIT_i + INV_i \quad (47)$$

$$\sum_j DS_{j,i1} = DD_{i1} \quad (48)$$

$$KS_j = KD_j \quad (49)$$

$$IT = SH + SG - CAB \quad (50)$$

The closure of the model is chosen to be representative of small island characteristics. We assume that the overall labour supply is exogenous. The volume of public expenditure and transfers to households are assumed to be exogenous because they meet the social well-being objectives (not maximization), which do not depend, in the short term, on economic conditions. As we consider a small open economy, we assume that it has no influence on world prices and that the level of the nominal exchange rate is fixed (Decaluwé, Martens and Savard, 2001; Trainar, Schubert and Letournel, 1992). Finally, since we consider a short-term equilibrium, we assume that total investment and sector-specific capital are also exogenous due to the slow rate of the adaptation of these volumes in the short term. The equality between savings and investment in the model is not constrained by respecting an external balance; thus, savings from abroad (current account deficit) can alleviate any domestic savings deficit, while conversely, any excess domestic savings can be invested abroad (current account surplus).

4. Scenarios and results

4.1 Carbon tax scenarios

To analyse the effects of the French carbon tax designed to facilitate energy transition, four types of simulations are proposed. All the simulations consist of analysing the impacts of a carbon tax of 100 €/tCO_2, which is consistent with the trajectory recommended by the French Act in 2015. These simulations differ in terms of revenue recycling schemes.

- In simulation 1, the carbon tax is considered without any mechanism for redistributing revenues. Carbon tax revenues increase the public budget.

- In simulation 2, tax revenues are returned to consumers as lumpsum transfers to maintain the final consumption.

- In simulation 3, tax revenues are used to reduce the existing social tax on the labour market to maintain the competitiveness of production sectors and tackle the unemployment problem.

- In simulation 4, revenues are used to subsidize the production of renewable energies to facilitate energy transition[4].

4.2 Environmental and macroeconomic impact analysis

The results of the four simulations are presented in Tables 1 and 2. We have also performed a sensitivity analysis of the results with different energy production substitution elasticity values[5] that show the model robustness (Appendix 2).

Table 1: Environmental energy sector impacts

		Simulation 1 T^C=100€/tCO_2	***Simulation 2*** T^C=100€/tCO_2 *Lumpsum Transfers to Households*	***Simulation 3*** T^C=100€/tCO_2 *Labour Social Taxes Decrease*	***Simulation 4*** T^C=100€/tCO_2 *Renewable Energy Sector Subsidy*
Variable	***Variable name***	***Variation rate (%)***			
Fossil fuel price	PC_{rff}	+44.72			
Fossil fuel final consumption	C_{rff}	-31.68	-29.61	-31.18	-30.77
Fossil energy production	XST_{nrjF}	-15.13	-13.13	-13.57	-18.62
Renewable energy production	XST_{nrjR}	+3.30	+5.11	+6.44	+98.56
Energy composite good	Q_{nrj}	-10.48	-8.52	-8.54	+0.8
Energy price	PC_{nrj}	+14.27	+14.94	+13.03	-0.17
Energy final consumption	C_{nrj}	-13.48	-11.37	-11.88	+0.03
Total emissions	EMS_{tot}	-21.37	-19.53	-20.29	-20.34
Electric mix: nrjF/nrjR (73.2/26.8)		69.2/30.8	69.3/30.7	69/31	47.8/52.2

[4] The simulated scenarios are not exactly the same as the one proposed by the French government, but the idea is maintained.

[5] As we are interested in the energy transition, the sensitivity of the results is understood in terms of the elasticity of substitution between the production of fossil energy and renewable energy. The initial elasticity was 1.5 in the model, and we have chosen a low value of 0.5 and a high value of 2.5.

Table 2: Macroeconomic impacts

		Simulation 1	***Simulation 2***	***Simulation 3***	***Simulation 4***
Variable	***Variable name***	***Variation rate (%)***			
Production					
Total production	XST	-0.89	-0.31	+0.28	-0.08
Intermediate products	CI	-1.11	-0.47	+0.25	-0.32
Value added	VA	-0.65	-0.11	+0.39	+0.07
Labour demand	LD	-1.11	-0.2	+0.67	+0.4
Unemployment rate	UN	+2.59	+0.46	-1.56	-0.93
Imports	IM	-2.98	-0.85	-1.73	-1.89
Exports	EX	-1.55	-1.58	+0.31	-1.19
Domestic demand for goods produced locally	DD	-0.88	-0.27	+0.27	-0.31
Composite goods	Q	-1.25	-0.37	-0.08	-0.59
Final consumption	C	-2.76	-0.55	-1.33	-1.06
Total intermediate demand	DIT	-1.11	-0.47	+0.25	-0.32
Total investment	INV	+0.49	-0.1	+2.18	-0.37
Income and savings					
Household income	YH	-1.13	+1.87	-0.4	+0.35
Household savings	SH	-1.13	+1.87	-0.4	+0.35
Government income	YG	+2.91	+0.06	-0.95	+1.55
Public consumption	G	-0.03	+0.48	-2.7	+0.26
Government savings	SG	+4.91	-0.68	+2.86	+2.16
Prices					
Production price (excluding taxes)	PP	+0.57	+1.37	-0.92	+1.21
Production price (including taxes)	PT	+0.58	+1.38	-0.91	+0.43
Import price	PM	+5.09	+5.09	+5.09	+5.09
Export price	PE	+0.78	+0.79	-0.16	+0.59
Price of local product on local market	PD	+0.58	+1.41	-0.92	+0.62
Product price in consumption	PC	+1.45	+2.12	+0.23	+1.48
Intermediate product price in consumption	PCI	+2.49	+3.20	+1.79	+2.31
General index of prices	PINDEX	+0.79	+0.03	-2.94	+0.06
Wage rate	W	-0.26	-0.05	+0.16	+0.09
Wage rate including payroll taxes	WT	-0.26	-0.05	-3.49	+0.09
Return on capital rate	R	-1.6	+0.2	-1.96	+0.41
Taxes					
Revenue from taxes on production	TIP	+0.11	+1.63	-0.24	-54.38
Social contributions	CS	-1.35	-0.27	-13.36	+0.81
Revenue from indirect taxes	TI	-5.49	-3.58	-4.78	-4.47
Government revenue from import	TIM	-3.53	-1.37	-2.22	-2.39
Revenue from direct taxes on household	DTH	-1.13	+1.87	-0.4	+0.35

Simulation 1

The introduction of a carbon tax drastically increases the price of imported fossil fuel by 44.72%. As a result, there is a substitution in energy production between fossil (-15.13%) and renewable energies (+3,3%). This substitution allows for a reduction in CO_2 emissions by 21.38%. However, the introduction of the carbon tax has negative effects on the overall economy. The detailed macroeconomic impacts are explained below.

If we look in detail at the energy sector, we can see that the electricity mix, which initially relied 26.77% on renewable and 73.23% on fossil energies, now relies 30.8% on renewable and 69.2% on fossil energies. The increase in the price of imported fossil fuel is then reflected in the increase in the price of intermediate inputs, which is greater in the production of fossil energy (+30.6% vs. +14.93%). The electricity price increases by 14.27%, which leads to a decrease in electricity production (-10.48%). Finally, since capital is fixed per branch, scenario 1 leads to a decline in the return on capital in the fossil energy sector (-23.05%).

At the aggregate level, economic activity slows down slightly (-0.89%), but this decrease is not uniform across sectors. In fact, fossil fuel price increases largely impact sectors that are dependent on fossil fuel uses. This pattern is mainly true for the transport sector, which is experiencing the greatest decline in production (-5.42%). Fossil fuel accounts for 27% of intermediate consumption in the transport sector. Fossil fuel products alone represent 16% of the expenses compared to 0.2% on average in the other sectors. Other sectors show more moderate declines (between -1.52% and -0.25%). The only exception is the building sector, which is experiencing a slight increase in its activity (+0.25%) due to its low use of fossil fuel and electricity goods (respectively, 0.11% and 0.73% of production costs) but that benefits mainly from an increase in the demand for investment purposes (+0.49%). Globally, the rise in fossil fuel and electricity prices increases the prices of intermediate consumption (2.49%), with repercussions on the consumption price (1.44%). This rise results in smaller demand in the local market (-1.75%).

The general decline in economic activity is reflected in the decreasing labour demand (-1.1%), which increases unemployment (2.58%). Household current income is falling (-1.13%) due to a decrease in the wage rate (-0.25%) and in the return on capital (-1.59%). Coupled with the increase in consumer prices, the demand for final consumption falls more than proportionally (-2.75%).

Finally, the state budget increases by 2.9% because of the introduction of this new carbon tax, which represents 4.8% of the budget, despite a decrease in all existing taxes. Therefore, the public deficit is reduced by 4.9%. The decline in household private savings is more than offset by the increase in public savings, which creates a trade surplus (+3.2%).

The main lesson that can be drawn from these macroeconomic linkages is that the introduction of a carbon tax of 100€/ton CO_2 would certainly initiate a substitution between fossil fuel and renewable energy production and thus reduce the level of current emissions, but this substitution would not be without negative impacts on the economic activity of the territory. Without going back to the need for such an environmental measure, this point argues in favour of introducing distributive policies to maintain the economic dynamic.

Thus, in the next simulation, we investigate the possibility of distributing tax revenues as lumpsum transfers to households.

Simulation 2

In the second simulation, tax revenues are recycled as lumpsum transfers to increase household income. As expected, this measure limits negative effects on economic activity through the support of household consumption. Household income, savings, and budget for consumption increase by 1.87%. Consumer prices increase by 2.12%. Finally, final consumption decreases somewhat less than in

scenario 1 (-0.55%). Therefore, the carbon tax has a smaller negative impact on domestic demand (-0.37%) and growth (-0.3%) in this scenario.
The effects of the tax on energy sector prices are similar to those in scenario 1, with an increase in the price of imported fossil fuel (44.72%) and electricity products (14.94%). We also observe a substitution between electricity production modes. However, this substitution is slightly less than that in scenario 1, bringing the energy mix to rely 30.67% on renewable energy and 69.33% on fossil energy, with a decrease in CO_2 emissions of 19.53%. Indeed, fossil energy production decreases less (-13.13% compared to -15.13% in scenario 1), while that of renewable origin increases more (5.10% against 3.30%). Ultimately, electricity production decreases less (-8.51%) due to a smaller decrease in the demand for final goods (-11.36%) and for intermediate goods (-0.56%). Apart from the electricity sector, the positive impact of the tax revenue recycling scheme on final consumption demand is observed in many sectors, particularly in the service sector, which is the main economic activity sector of the territory. Economic activity is supported by household consumption. The demand for intermediate goods decreases less than in the previous scenario, despite a greater increase in intermediate consumption price (3.20%). Therefore, aggregate labour demand decreases less in this scenario than in scenario 1 since services employ 77.79% of the workforce, a point reflected in the unemployment rate, which increases but to a lesser extent (0.45%).
The state budget no longer benefits from carbon tax revenues. However, the increase in household income tax (1.87%) and production taxes (1.62%), mainly carried here by increasing renewable energy production, leads to a balanced state income (0.05%), resulting in an increase in the public deficit (0.68%). This deficit is partly offset by the increase in private savings (1.87%), which also creates, to a lesser extent, a trade surplus (0.73%). Indeed, while exports decrease similarly in both scenarios (-1.55% and -1.57%, respectively), imports decrease less in the second scenario because of higher demand in the local market.

This compensatory measure has the expected results since the introduction of the carbon tax initiates a substitution in the electricity production modes and thus reduces CO_2 emissions, while the negative impact on economic activity is less than in the previous scenario due to household consumption support. However, we can question whether there are other compensatory measures that would be more effective in supporting economic activity. In the third scenario, we test the possibility of using carbon tax revenues to reduce taxes in the labour market.

Simulation 3

In the third scenario, tax revenues are used to reduce the social contribution rate paid by firms (-14%), which leads to a reduction in the net wage rate (-3.49% on average). This reduction benefits economic activity, as the demand for labour increases (0.67%), the unemployment rate decreases (-1.56%) and production increases by 0.28%. This measure more than compensates for the negative effects presented in the first scenario.
Regarding the energy sector, the introduction of the carbon tax again leads to a reduction in CO_2 emissions, and this decrease is greater than that in scenario 2 (-20.29%). The electricity mix now relies 31.04% on renewable energy and 68.96% on fossil energy. In fact, the decrease in fossil energy production is slightly less than in scenario 2 (-13.57%) and is offset by a rise in renewable energy production (6.44%); therefore, the decrease in overall energy production is almost identical (-8.53%) to that in the previous scenario. Thus, since the variations in production volumes are relatively small between scenarios 2 and 3, we can conclude that the introduction of the tax has similar effects on the energy sector, regardless of the recycling schemes. However, the effects on prices are different; we observe a smaller increase in the energy price (13.03%) because of the decrease in the labour cost

(-4.29%), which decreases the value added price (-0.75% for the renewable origin sector and -12.07% for the fossil origin sector).
The effects at the macroeconomic level are quite different since they become positive for the production side and negative for households and for the government. Indeed, the reduction in the social contribution rate makes it possible to support economic activity by reducing the cost of labour for firms, which increases their demand for work and therefore their value added (0.39%) and their intermediate consumption (0.25%). Outside the energy sector, the decline in the cost of labour benefits all sectors of the economy, whose production increases between 0.38% and 2.18%. Only the transport sector is still suffering directly from the increase in the price of fossil fuel, which again sees its production decreasing by 3.76%. However, the general price level is decreasing in this scenario (-2.94%). Indeed, the decrease in the cost of labour has a negative impact on the producer price, which contrasts with the other two scenarios (-0.92%). This fall in prices leads to a decrease in the export price (-0.16), which makes local production more competitive and therefore allows for an increase in exports (0.31%). Moreover, this process makes imports more expensive, leading to a greater decrease in imports (-1.73%). As a result, the amount of composite goods placed in the local market decreases slightly (-0.08%). Finally, this decrease in the local production price leads to a lesser price increase in the final market than in the previous scenarios (0.23%). However, this decrease does not support the level of final consumption, which is less than that in scenario 2 (-1.33%). In fact, the decrease in unemployment (-1.56%) caused by the increase in the demand for work does not make it possible to increase household income (-0.4%). The decline in return on capital (-1.96%) more than offsets the increase in the gross wage rate (0.16%) and the demand for work.
The state budget is penalized by this measure (-0.95%) since its total revenue decreases. Indeed, even if the decrease in revenue from social contributions (-13.36%) is offset by the revenues from the new carbon tax, the decrease in imports and household income leads to drops in import (-2.22%) and income taxes (-0.4%). Finally, the fall in prices also influences public spending, which is decreasing (-2.7%), allowing for the public deficit to decrease (2.86%), despite the decrease in the state budget. In contrast to the previous scenario, the increase in public savings offsets the decline in public savings, with a surplus trade balance (2.05%).

This third scenario shows that a compensatory measure aimed at reducing social contributions will have a positive effect on the productive activity of the territory since such a measure benefits almost all economic activities. Moreover, despite the decrease in unemployment, this scenario does not allow for a positive impact on households. In addition, the fall in the net wage rate has a negative effect on price levels, favouring the competitiveness of the territory but penalizing local resources.

Simulation 4

In the last scenario, part of the carbon tax revenue (60%) is transferred to the renewable energy production sector as a subsidy. This amount lowers the tax rate on production, which now represents a subsidy of 41%. The negative effects of the tax on the global activity of Reunion Island are less than in scenario 1.

This measure mainly affects the energy production sectors and allows for a real substitution since it makes it possible to obtain an electricity mix based 52,2% on renewable energy and 47,8% on fossil energy. Therefore, this scenario is the only one where renewable energy becomes dominant in the mix. However, total emissions do not decrease more than in the previous scenarios (-20.34%). In fact, this measure slightly increases the price of final energy (-0.17%) and therefore decreases its relative price to other goods. In this case, the carbon signal price does not play its dissuasive role in both the production of electricity and the final energy demand, which increases by +0.8% regardless of whether for final energy consumption (+0.03%) or for intermediate energy consumption (+1,54%).

The increase in renewable energy production has an impact on the aggregate results. Indeed, the increase in renewable energy production (+98.56%) makes it possible to increase the demand for work in this sector (+247.14%)[6]. The increase in labour demand in the energy sector makes it possible to increase the aggregate demand for work (+0.4%) and thus reduce unemployment (-0.93%). This increase and the increase in the return on capital (+0.41%) thus make it possible to increase household income and savings (+0.35%). However, as in scenario 2, this increase does not make it possible to increase aggregate final consumption (-1.06%) since the decrease in demand for fossil and transport goods (the demand for good energy increases this time, from the decrease in relative price) offsets the increase in other sectors.

Because a part of the revenue from the carbon tax is not redistributed here, the state budget increases by +1.55%. This increase makes it possible to reduce the public deficit (+2.16%). Thus, the increase in public and private savings goes hand in hand with a surplus trade balance, given that the decrease in imports (-1.89%) is mainly due to the decrease in the imports of a fossil good (-20.34%), despite a decrease, but fewer exports (-1.19%) due to the increase in export prices (+0.59%).

This last scenario shows that subsidizing the production of renewable energy is most effective if the objective pursued is the transition towards a 100% renewable electricity mix. However, due to the downward influence of the carbon price, this scenario does not reduce CO_2 emissions more than in previous cases, and the signal price no longer plays a role, as final energy demand increases slightly.

5. Policy discussion and conclusions

5.1 Policy discussion

Introducing a new carbon tax enables the substitution between fossil energy production and renewable energy production and reduces CO_2 emissions. It is one of the levers for initiating an energy transition and encouraging behavioural change. However, this tax also has negative effects on the economy and leads to hostile public opinion. It is therefore necessary to accompany this policy with compensatory measures aimed at reducing these negative impacts (Liu and Lu, 2015). In that sense, Bibas *et al.* (2016), in their study on an acceptable low carbon scenario, showed that the carbon tax (notably) could represent an effective climate policy and make it possible to reduce the household budget dedicated to energy services, but on the condition that additional funding is put in place to build the social acceptability of emission reduction measures and the implementation of energy transition, reducing the vulnerability of households and the economy to rising energy prices.

We have seen that the three compensatory measures presented above allow for this reduction in negative impacts. Notably, the carbon tax generates revenue that can be used to lower taxes, support low-income households, offset the negative impacts of the carbon tax on households and businesses, improve the growth potential of the economy and invest in the energy transition. However, depending on these situations, the choice of revenue recycling does not support the same economic actors. Indeed, in simulation 2, the lumpsum repayment to households can support household income, but it is not enough to offset the increase in prices resulting from the increase in primary and secondary energy

[6] As the increases are relative, the variations are very important because the initial base is small (0.59% of the production and 0.48% of the payroll).

prices. As a result, the repayment does not support local economic production activity through the consumption channel, as one might expect. In the third simulation, it is the private sector that benefits from the revenues of the carbon tax via the reduction of social contributions. As a result, productive activity increases but does not translate into an increase in household consumption and income. To summarize, if in both scenarios, the environmental objectives are achieved, in one case, the increase in income does not allow for an increase of production, and in the other, the increase in production does not allow for an increase of income. These simulations show that the effects of these two measures are actor-specific and that particular attention must be paid to the price effects in the transmission channels. Finally, the last scenario is the most efficient from the point of view of the transition towards renewable energies, but the falloff in energy price prevents the carbon price signal from playing its role in reducing final energy intermediate consumption and emissions. This issue is important, as in the context of fighting against climate change, energy efficiency is an important objective of the energy transition policy in France (Energy Transition for Green Growth Law, 2015). The impact on the overall economy (production and consumption side) is slightly better than in the other scenarios, as global production increases, and final consumption decreases slightly.

The ideal recycling of carbon pricing revenue will strongly depend on the political strategy to be pursued and on French people's perception of the carbon tax policy. As we have seen in France with the "Yellow Vest" protests, household low purchasing power is one of the greatest obstacles to higher carbon prices. The resulting abolition of the carbon tax echoes other failures in France in introducing a carbon tax (before 2018, 2001 and 2010). Based on these experiences, Berry and Laurent (2019) put forward several criteria for the success of a carbon tax, including, in particular, in addition to its ecological efficiency, social justice and political acceptability, social justice being a real lever for ecological transition. These months of protests in France have indeed highlighted a lack of understanding among many citizens about how to carry out the ecological transition in France with an incomprehension that the tax revenues are not only marginally affected by the ecological transition tax exemptions that feed the feeling of an unevenly shared and unfair effort. Indeed, the carbon tax can represent strong household budget constraints and weigh more heavily on modest households as a proportion of their income, particularly considering the difficulty some face in reducing their consumption in the short term and, above all, a lack of accessible low-carbon alternatives for getting around (Guillou and Perrier, 2019; Saujot *et al.* 2019). Therefore, our study shows that returning tax revenues as uniform lumpsum transfers can increase household disposable income and favour final consumption. Our results are in line with Saujot *et al.* (2019). They show that the implementation of a carbon tax should be accompanied by an annual "ecological transition premium" to preserve household budgets and consequently avoid a reduction in their welfare, especially for the most constrained households. The macroeconomic model simulation for Austria conducted by Kirchner *et al.* (2019) also highlighted that carefully designed CO_2 tax policies with recycling schemes can potentially provide an equitable double dividend, which could increase the social and political acceptance of a CO_2 tax policy, allowing for these measures to play an important role in achieving GHG emission targets and providing incentives to invest in low-carbon or carbon-neutral technologies.

A wider household analysis with larger models that combine micro- and macroeconomic analyses will allow for the precise assessment of the equity and efficiency impacts and determination of whether this type of recycling strategy can render the carbon tax reform progressive.

An interesting perspective that could be tested is a mixed recycling option. We have studied three polar schemes, but a hybrid revenue-recycling scheme might be desirable to compile positive effects. Such a scheme is often applied in countries with carbon pricing policies such as Australia, Switzerland and Sweden (Klenert *et al.*, 2017). In the French case, the study conducted by Gallonec and Combaud

(2019) highlights that mixed recycling methods seem to be more favourable than full recycling methods for either households or companies, both in terms of GDP and employment. Revenues from carbon-pricing schemes are rarely recycled in any single way and incorporate multiple uses of revenue. However, this would require testing several simulation plans to cross-recycle recycling proportions in the three possible positions to see if certain mixes are better than others and possibly identify an "optimal" mix. This will therefore be the subject of future research.

5.2 Conclusions

The energy sector faces many challenges in terms of reducing greenhouse gas emissions, but this point is all the more true in ultramarine economies subject to strong environmental and demographic pressures. Fossil fuels currently occupy a central place in the Reunion Island's electricity production system and will have to be drastically reduced to favour the development of renewable energies. This energy transition is confronted with strong technological interlocks that must be overcome by implementing appropriate economic policies. The paper evaluates the macroeconomic and environmental effects of introducing a carbon tax based on a computable general equilibrium model specifically built and calibrated to take into account all island specificities (GetRun-NRJ). The increase in the French carbon tax established in 2014 was abandoned due to the popular "Yellow Vest" protest. The Yellow Vests appeared concerned with the disproportionate burden that the carbon tax could impose on low-income households. The increasing revenues from the carbon tax were mostly used to fund the budget rather than being redistributed to households, raising concerns over the distributive effects of the policy. To facilitate the public acceptance of a carbon tax, three revenue-recycling strategies have been studied in simulations: compensation via lumpsum transfers to maintain household purchasing power, the use of tax revenues to reduce existing taxes on labour to tackle unemployment and a revenue earmark to promote renewable energies.

The results of the simulations show that the tax allows for a substitution between renewable and fossil energies and a decrease in CO_2 emissions, but it negatively affects the global economic activity of the island. However, recycling tax revenues can allow for positive macroeconomic effects by supporting different actors. Our three polar simulations will support either the production side or the consumption side of the economy.

We believe that our model, which takes into account the energy characteristics of insular territories, and our simulations, which emphasize the gain from particular revenue recycling, can serve as a benchmark for policymakers to design their policies in a particular island context.

Research perspectives emanate from this work, allowing for the analysis to be further completed.

First, as mentioned before, an analysis of the mixes of the three scenarios provided here would allow us to identify if certain mixes are more effective than others and if it is possible to determine an optimal mix.

Second, the energy sector in the model is currently relatively aggregated. We consider two branches for the production of secondary energy (fossil and renewable branches). A methodological breakthrough would be a further disaggregation of the energy sector. This disaggregation can be done according to the physically available potential of renewable energies and according to the CO_2 content of fossil fuels. Our study (Selosse *et al*, 2018) revealed that biomass plays an important role in the

future electricity mix of Reunion Island. It therefore seems appropriate to treat it separately from other renewable energies.
Third, as in many CGE models, the study assumes a representative consumer and therefore neglects household heterogeneity. In other words, the distributive mechanisms described above are functional distributions among production factors, wages, profits and revenues but not individual income inequalities. An additional evaluation including household disaggregation would illuminate the analysis on social justice by taking into account interpersonal redistribution impacts.

Based on the strong reticence of the French people since the "Yellow Vest" movement, it might appear challenging to reintroduce the carbon tax in France unless the fairness of the policy, through a tax revenue recycling scheme, is largely improved. The model and the proposed scenarios offer a unique and useful framework for analysing the macroeconomic and environmental impacts of the carbon tax on Reunion Island. This work opens up a relevant field of research and discussion on carbon tax impacts in a non-interconnected island setting.

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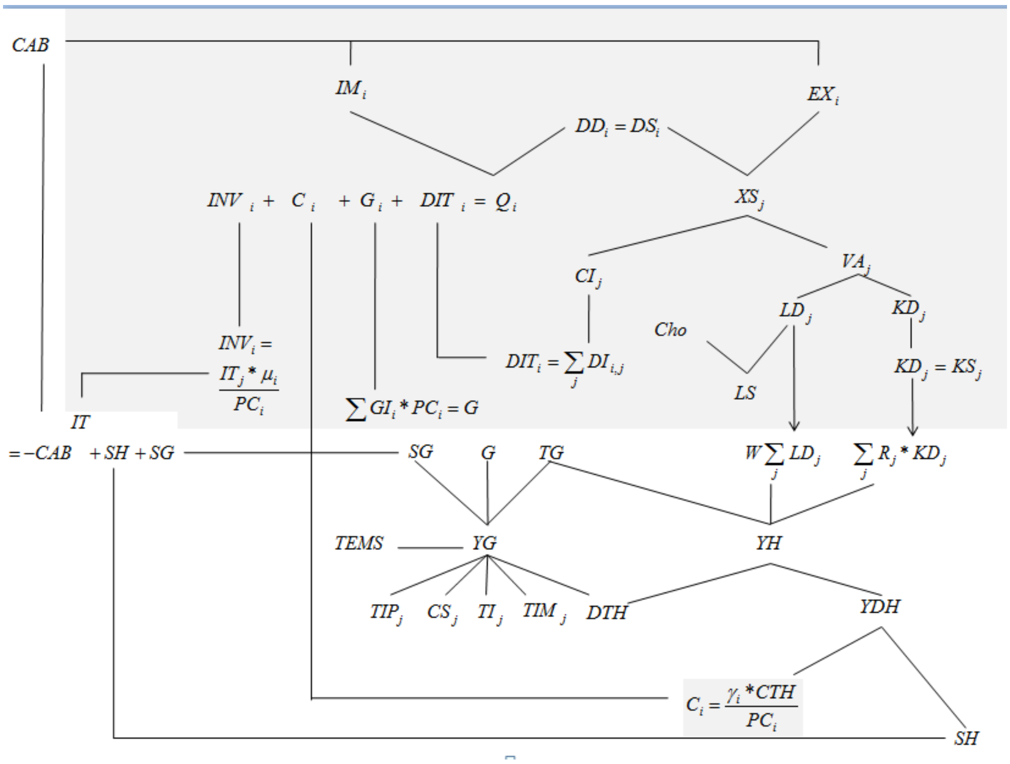
8. Appendix

Appendix 1: Interdependence mechanism in GetRun



Appendix 2: Sensitivity analysis

Table 1: Environmental energy sector impacts

		Simulation 1 ***T^C=100€/tCO_2***		***Simulation 2*** ***T^C=100€/tCO_2*** ***Lumpsum Transfers to Households***		***Simulation 3*** ***T^C=100€/tCO_2*** ***Labour Social Taxes Decrease***		***Simulation 4*** ***T^C=100€/tCO_2*** ***Renewable Energy Sector Subsidy***	
Variable		***Var (%)***	***σ= 0.5/σ= 2.5***	***Var (%)***	***σ= 0.5/σ= 2.5***	***Var (%)***	***σ= 0.5/σ= 2.5***	***Var (%)***	***σ= 0.5/σ= 2.5***
Fossil fuel price	PC_{rff}	+44.72 (+44.72/+44.72)							
Fossil fuel final consumption	C_{rff}	-31.68	-31.69/-31.67	-29.61	-29.61/-29.60	-31.18	-31.19/-31.17	-30.77	-30.77/-30.59
Fossil energy production	XST_{nrjF}	-15.13	-13.71/-16.23	-13.13	-11.71/-14.21	-13.57	-12.02/-14.75	-18.62	-18.62/-32.25
Renewable energy production	XST_{nrjR}	+3.31	-0.79/+6.34	+5.11	+1.07/+8.1	+6.44	+1.95/+9.78	+98.56	+ 98.56/+133.01
Energy composite good	Q_{nrj}	-10.48	-10.48/-10.48	-8.52	-8.51/-8.53	-8.54	-8.55/-8.54	+0.8	+0.8/+1.03
Energy price	PC_{nrj}	+14.27	+14.22/14.33	+14.94	+14.88/+14.99	+13.03	+12.98/+13.08	+0.17	+0.17/+0.31
Energy final consumption	C_{nrj}	-13.48	-13.45/-13.51	-11.37	-11.33/-11.4	-11.88	-11.86/-11.91	+0.03	+0.02/+0.14
Total emissions	EMS_{tot}	-21.37	-21.2/-21.52	-19.53	-19.35/-19.68	-20.29	-20.10/-20.44	-20.34	-19.34/-21.13
Electric mix: nrjF/nrjR (73.2/26.8)		69.2 /30.8	70.4/29.6 68.3/31.7	69.3/30.7	70.5/29.5 68.5/31.5	69/31	70.2/29.8 68/32	47.8/52.2	47.1/52.9 44.3/55.7

Table 2: Macroeconomic impacts

		Simulation 1		***Simulation 2***		***Simulation 3***		***Simulation 4***	
Variable		***Var (%)***	***σ= 0.5/σ= 2.5***	***Var (%)***	***σ= 0.5/σ= 2.5***	***Var (%)***	***σ= 0.5/σ= 2.5***	***Var (%)***	***σ= 0.5/σ= 2.5***
Production									
Total production	XST	-0.89	-0.9/-0.89	-0.31	-0.31/-0.30	+0.28	+0.28/+0.29	-0.08	-0.09/-0.08
Intermediate products	CI	-1.11	-1.11/-1.11	-0.47	-0.46/-0.47	+0.25	+0.25/+0.25	-0.32	-0.3/-0.35
Value added	VA	-0.65	-0.66/-0.65	-0.11	-0.12/-0.11	+0.39	+0.38/0.40	+0.07	+0.03/+0.09
Labour demand	LD	-1.11	-1.13/-1.09	-0.2	-0.21/-0.19	+0.67	+0.65/+0.69	+0.4	+0.23/+0.52
Unemployment rate	UN	+2.59	+2.63/+2.56	+0.46	+0.49/+0.43	-1.56	-1.51/-1.60	-0.93	-0.53/-1.20
Imports	IM	-2.98	-2.98/-2.99	-0.85	-0.84/-0.86	-1.73	-1.72/-1.73	-1.89	-1.82/-1.92
Exports	EX	-1.55	-1.55/-1.55	-1.58	-1.57/-1.58	+0.31	+0.31/+0.31	-1.19	-1.21/-1.19
Domestic demand for goods produced locally	DD	-0.88	-0.88/-0.88	-0.27	-0.28/-0.27	+0.27	+0.27/+0.28	-0.31	-0.33/-0.3
Composite goods	Q	-1.25	-1.25/-1.25	-0.37	-0.37/-0.37	-0.08	-0.08/-0.08	-0.59	-0.59/-0.58
Final consumption	C	-2.76	-2.77/-2.75	-0.55	-0.56/-0.55	-1.33	-1.34/-1.32	-1.06	-1.2/-0.97

Total intermediate demand	DIT	-1.11	-1.11/-1.12	-0.47	-0.46/-0.47	+0.25	+0.25/+0.25	-0.32	-0.3/-0.35
Total investment	INV	+0.49	+0.5/0.49	-0.1	-0.09/-0.1	+2.18	+2.18/2.17	-0.37	-0.29/-0.41
Household income	YH	-1.13	-1.15/-1.12	+1.87	+1.87/+1.88	-0.4	-0.42/-0.39	+0.35	+0.19/+0.46
Household savings	SH	-1.13	-1.15/-1.12	+1.87	+1.87/+1.88	-0.4	-0.42/-0.39	+0.35	+0.19/+0.46
Government income	YG	+2.91	+2.9/+2.91	+0.06	+0.05/+0.07	-0.95	-0.94/-0.95	+1.55	+1.53/+1.56
Public consumption	G	-0.03	-0.04/-0.03	+0.48	+0.47/+0.48	-2.7	-2.7/-2.7	+0.26	+0.21/+0.3
Government savings	SG	+4.91	+4.91/+4.9	-0.68	-0.69/-0.68	+2.86	+2.87/+2.85	+2.16	+2.2/+2.11
Production price (excluding taxes)	PP	+0.57	+0.56/+0.57	+1.37	+1.36/-1.37	-0.92	-0.93/-0.92	+1.21	+1.12/+1.28
Production price (including taxes)	PT	+0.58	+0.57/0.59	+1.38	+1.37/+1.38	-0.91	-0.91/-0.90	+0.43	+0.36/+0.5
Import price	PM	+5.09	+5.1/+5.08	+5.09	+5.10/+5.08	+5.09	+5.10/+5.08	+5.09	+5.15/+5.05
Export price	PE	+0.78	+0.78/+078	+0.79	+0.79/+0.79	-0.16	-0.16/-0.16	+0.59	+0.6/+0.59
Price of local product on local market	PD	+0.58	+0.57/+0.59	+1.41	+1.4/+1.41	-0.92	-0.92/-0.91	+0.62	+0.58/+0.66
Product price in consumption	PC	+1.45	+1.44/+1.45	+2.12	+2.12/+2.12	+0.23	+0.23/+0.24	+1.48	+1.46/+1.50
Intermediate product price in consumption	PCI	+2.49	+2.49/+2.49	+3.20	+3.20/+3.20	+1.79	+1.79/+1.79	+2.31	+2.32/+2.31
General index of prices	PIND EX	+0.79	-0.8/-0.78	+0.03	+0.02/+0.03	-2.94	-2.94/-2.33	+0.06	+0.02/+0.09
Wage rate	W	-0.26	-0.26/-0.25	-0.05	-0.05/-0.04	+0.16	+0.15/+0.16	+0.09	+0.05/+0.12
Wage rate including payroll taxes	WT	-0.26	-0.26/-0.25	-0.05	-0.05/-0.04	-3.49	-3.49/-3.5	+0.09	+0.05/+0.12
Return on capital rate	R	-1.6	-1.62/-1.58	+0.2	+0.18/+0.21	-1.96	-1.98/-1.94	+0.41	+0.22/+0.56
Revenue from taxes on production	TIP	+0.11	+0.01/+0.18	+1.63	+1.53/-1.7	-0.24	-0.34/-0.16	-54.38	-53.65/-54.92
Social contributions	CS	-1.35	-1.37/-1.33	-0.27	-0.29/-0.25	-13.36	-13.36/-13.36	+0.81	+0.54/+0.98
Revenue from indirect taxes	TI	-5.49	-5.46/-5.51	-3.58	-3.54/-3.61	-4.78	-4.75/-4.81	-4.47	-4.35/-4.59
Government revenue from import	TIM	-3.53	-3.53/-3.54	-1.38	-1.36/-1.39	-2.22	-2.21/-2.23	-2.39	-2.33/-2.43
Revenue from direct taxes on household	DTH	-1.13	-1.15/-1.12	+1.87	+1.87/+1.88	-0.4	-0.42/-0.39	+0.35	+0.19/+0.46